AD-A018 169

A018169

RIA-76-U24

ADA018169

USADACS Technical Library
5 0712 01014353 4

Report 2150

AN ANALYSIS OF EFFECTS OF ELECTROMECHANICAL VIBRATION ON SELECTED SPECIMENS

June 1975

TECHNICAL
LIBRARY

Approved for public release; distribution unlimited.

U. S. ARMY MOBILITY EQUIPMENT RESEARCH AND DEVELOPMENT CENTER
FORT BELVOIR, VIRGINIA

Destroy this report when no longer needed.
Do not return it to the originator.

The citation in this report of trade names of commercially available products does not constitute official endorsement or approval of the use of such products.

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER 2150	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) AN ANALYSIS OF EFFECTS OF ELECTRO-MECHANICAL VIBRATION ON SELECTED SPECIMENS		5. TYPE OF REPORT & PERIOD COVERED Research: November 1973 through April 1975 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) 1LT N. R. Moody W. H. Baer H. E. Horner		8. CONTRACT OR GRANT NUMBER(s)
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Mobility Equipment Research and Development Center ATTN: AMXFB-RMM Fort Belvoir, Virginia 22060		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Project 1G762708AH67
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Mobility Equipment Research and Development Center Fort Belvoir, Virginia 22060		12. REPORT DATE June 1975 13. NUMBER OF PAGES 32
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) Unclassified 15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This investigation was conducted under the Mossbauer Surface Stress Analyzer development program to provide a preparatory basis for eventual quantitative analysis of residual stress levels.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Cold working
Dimensional stability
Mechanical properties
Residual stress
Steel
Thermal stress relief
Vibratory stress relief
Welding

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

An analysis of the effects of vibration on residual stress and distortion was performed on U-bend samples. Welded tensile specimens were also subjected to vibration to determine its effect on mechanical properties. A third test, subjecting a welded plate to vibration, was conducted to ascertain if these induced vibrations would cause crack nucleation and/or propagation.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

PREFACE

This investigation was conducted under the Mossbauer Surface Stress Analyzer development program to provide a preparatory basis for eventual quantitative analysis of residual stress levels. This work was under the technical direction of Mr. William H. Baer, Chief, Metallurgy Research Team, under general supervision of Emil J. York, Chief, Materials Engineering Division. Mr. Emerson W. Asher, Mr. George Farmer, Dr. N. E. Dowling, and Dr. H. J. Konish offered suggestions and constructive criticism.

SUMMARY

An analysis of the effects of vibration on residual stress and distortion was performed on U-bend samples. Welded tensile specimens were also subjected to vibration to determine its effect on mechanical properties. A third test, subjecting a welded plate to vibration, was conducted to ascertain if these induced vibrations would cause crack nucleation and/or propagation.

Residual stresses and stress relief are briefly discussed to provide background information. Previous studies are also presented to give some insight into what experimentation has been done. In this analysis, the U-bends were divided into four groups, each undergoing different treatments to enable a comparison of the effectiveness of each treatment. The U-bends underwent measurements in a variety of positions before and after milling to detect distortion. The welded tensile specimens were divided into three groups, each also undergoing different treatments for comparison purposes. The mechanical properties of the welded tensile specimens were determined by tensile testing. The welded test plate was subjected to several vibration tests of various frequency and duration, after each of which the plate was X-rayed and magnafluxed to detect cracks.

The data for each group for both the U-bend and tensile specimens were statistically treated to determine the mean and standard deviation. Of specific interest in the U-bend measurements was the difference between the before and after milling measurements, which indicates the amount of distortion. The data for each type of specimen were also analyzed by the student t distribution to determine the appropriate "p" values. The p value is the probability that the difference is significant because of treatment or because of random sample distribution.

The numerical results enable only a qualitative comparison with regard to residual stress relief but lead to the conclusion that vibratory stress relief does not suffice for a U-shaped specimen in relieving stress or giving dimensional stability. The tensile test on the welded tensile specimens shows that mechanical properties are unaffected by vibration. The welded test plate shows no evidence of crack nucleation and/or propagation for this particular weld and materials. Enough information from various experiments and reports has been obtained to state that vibratory stress relief is not an acceptable substitute for thermal stress relief.

CONTENTS

I INTRODUCTION

II BACKGROUND

III ANALYSIS

IV CONCLUSIONS

ILLUSTRATIONS

TABLES

AN ANALYSIS OF EFFECTS OF ELECTROMECHANICAL VIBRATION ON SELECTED SPECIMENS

I. INTRODUCTION

1. **General.** Residual stresses have long posed a serious problem to manufacturers and consumers of many iron and steel products. These stresses can cause rejection of items because of distortion or lead to unexpected failure, which at times may be catastrophic. The usual method of stress relief is thermal treatment which is often expensive and time-consuming. The search for a lower cost stress relief method has led to the investigation of electromechanically induced vibration and its application by a few manufacturers in stress relief equipment. The vibration method's effectiveness is questionable because of a lack of experimental data. The Metallurgy Research Team, Materials Engineering Division (MED), of the Mobility Equipment Research and Development Center, Fort Belvoir, Virginia, has undertaken vibratory stress relief experimentation to gather more data and has treated them statistically to attempt more definitive conclusions of experimental results. Eventually, these data will be utilized and expanded by quantitative determination of residual stress with the Mossbauer Surface Stress Analyzer.

II. BACKGROUND

2. **Stress.** Whenever an external force acts on a body, equilibrium is maintained by internal forces resisting the external actions. These internal forces are usually expressed by stress, the force acting over a certain area.[1] Residual stresses are internal stresses existing in a body after external forces are removed. These residual stresses are considered to be elastic stresses with a maximum value equaling the elastic limit. Any stresses exceeding this value are relieved by plastic deformation of the body. Residual stresses are produced whenever nonuniform plastic deformation occurs, which may be by mechanical processes, quenching, precipitation, welding, nitriding, or carburizing.[2]

These stresses are responsible for distortion and dimensional instability of bodies. Various machining operations, which remove material and the residual stress it contains, cause material shifts to reestablish equilibrium.

3. **Stress Relief.** Stress relief is often performed to reduce or eliminate distortion caused by residual stresses. Residual stresses will slowly relieve themselves by daily

---

[1] George E. Dieter, Jr., *Mechanical Metallurgy*, McGraw-Hill Book Company (1961), p. 5.

[2] *Ibid*, p. 393-397.

thermal cycles, but this process is greatly accelerated by heating the material to high temperatures. This operation is commonly known as thermal stress relief – a proven and effective method.[3]

A technique has recently emerged involving vibration to relieve or redistribute residual stresses in order to reduce distortion and dimensional instability. A manufacturer of a vibratory stress relief equipment claims it does not completely replace thermal stress relief but that it is a lower cost method to reduce residual stress at highly stressed areas without inducing microstructural changes or oxidation as would occur in thermal treatment.[4]

Vibratory stress relief uses a motor-driven, adjustable eccentric weight to excite structures by sinusoidal waves. This vibrational energy causes the metal crystals in a stressed condition to move slightly and reestablish their equilibrium to a lower stress condition.[5] In an unpublished MED report, Dr. N. E. Dowling stated that he knew of only two phenomena which could result in stress relaxation by vibration. One is "deformation in highly stressed regions due to dynamic loads caused by vibrations (generating) sufficient heat to cause stress relief."[6] This would probably entail a change in mechanical properties. The second is "if the dynamic loads are high enough to cause large cyclic strains (greater than 0.01 inch/inch) the residual stresses in the highly strained regions could relax due to repeated plastic deformation."[7] An attempt was made to measure strains caused by vibration in a large steel bumper as shown in Figure 1, but no strains of the necessary magnitude could be recorded. Strains of this magnitude are usually sufficient to initiate cracks in most metals and to cause fatigue damage. In another unpublished MED report, Dr. H. J. Konish states "that dimensional stability cannot be the sole criterion for evaluating the effectiveness of vibratory stress relief. Also important are the long-term effects of stress relief by vibrations. The presence of weld material creates brittle zones, the regions in which cracks can readily nucleate and propagate leading to eventual failure."[8]

4. Previous Studies. Vibratory stress relief is presented as a lower cost method of reducing residual stress to achieve dimensional stability. The possibility of vibratory stress relief achieving its claims has spurred a few investigations and experiments.

---

[3] George E. Dieter, Jr., *Mechanical Metallurgy*, McGraw-Hill Book Company (1961), p. 417.

[4] *VSR-Vibration Stress Reduction and Metal Stabilization Process Brief*, Martin Engineering Company, p. 1.

[5] *Ibid*, p. 4.

[6] Dr. H. E. Dowling, *Comments on Residual Stress Removal by Vibration*, private MED report.

[7] *Ibid.*

[8] Dr. H. J. Konish, *Some Long Term Effects of Vibratory Stress Relief*, private MED report.

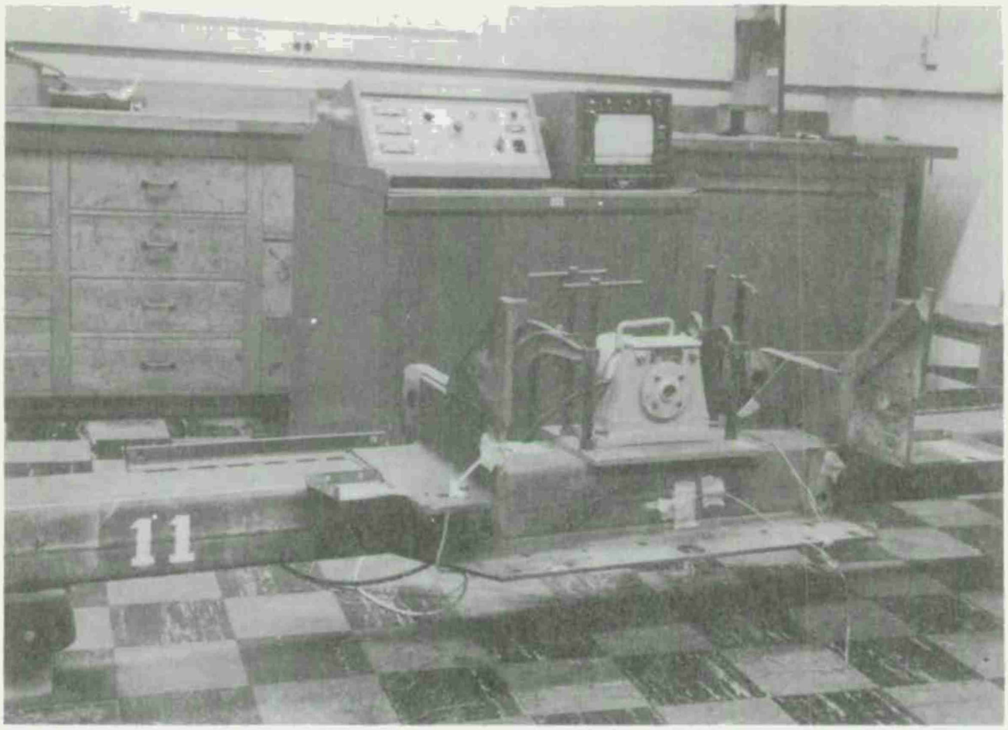


Figure 1. Measurement of strains caused by vibration in a large steel bumper.

Vibratory stress relief equipment manufacturers' literature is often accompanied by letters from equipment user's claiming successful use on various shapes, as in the machining of U-shaped openings. Naval Ordnance Systems Command has published a report on their experimentation of the effects of vibration on stress reduction and dimensional stability. Their test specimens were chosen to produce welding stresses, machining stresses, cold-forming stresses, and heat-treat stresses. The specimens representing each type of stress were divided into three groups for comparison. One group was thermally stress relieved; a second group was left as formed; and the third group was vibrationally conditioned. The Navy investigators concluded that vibratory stress relief appears feasible but that the uniform reduction of stress levels obtained by thermal treatments was not attained using vibratory methods and that there is insufficient evidence available to insure success by this method.[9]

III. ANALYSIS

5. **Purpose and Outline.** This analysis was undertaken to provide more definitive data to determine the effects of vibratory stress relief on residual stresses and dimensional

---

[9] *The Effectiveness of Vibratory Stress Relief,* Naval Ordnance Systems Command, Naval Ordnance Station, Louisville, Kentucky (1971).

stability on low carbon steel. It concentrates on a particular sample, a cold-formed U-bend (Figure 2).

The U-bends were divided into four groups to compare the effects of vibration on residual stress and dimensional stability (Table 1). One group was left in the as-formed condition, a second group was thermally treated to represent a condition of no residual stress, and the two remaining groups were vibrated. The U-bends were measured before and after machining a flat spot on the outer radius to determine the amount of U-bend movement. These data were treated statistically by the student t test to indicate if the difference between groups was caused by treatment or by random sample distribution.

Table 1. U-Bend Groups

Group	Condition	Stress Relief Method
1A-5A-7A	Vibrated at 20 percent motor eccentricity	Vibration
2A-3A-4A	Vibrated at 45 percent motor eccentricity	Vibration
6A-8A	As-formed	No stress relief
1B through 5B	Hot-worked	Complete stress relief

Vibration can induce damaging fatigue cracks, especially in the brittle material of welds and accompanying heat-affected zones. To facilitate examining the possibility of crack initiation and propagation in this area, a weld test plate was fabricated from which a vibration plate and a number of tensile specimens were cut.

The welded vibration plate was designed to investigate the possibility of nucleation and/or propagation of cracks through the brittle weld material and heat-affected zones. The plate was vibrated through a series of harmonic peaks for various lengths of time, then X-rayed and magnafluxed after each vibration to detect the presence of cracks.

The tensile specimens were used to determine the effects of vibration on mechanical properties. For comparison of results, the specimens were divided into three groups: thermally relieved, as-welded, and vibrated. The mechanical property results also were statistically treated using the student t test to indicate if the difference between groups was attributable to treatment or to sample distribution.

The U-bends to be vibrated were clamped to the base of the vibrator's eccentric motor, as shown in Figure 3, with the transducer clamped to the curved portion to transmit vibration data to the control unit. Groups 1A-5A-7A and 2A-3A-4A were vibrated with motor eccentricity set at 20 and 45 percent, respectively.

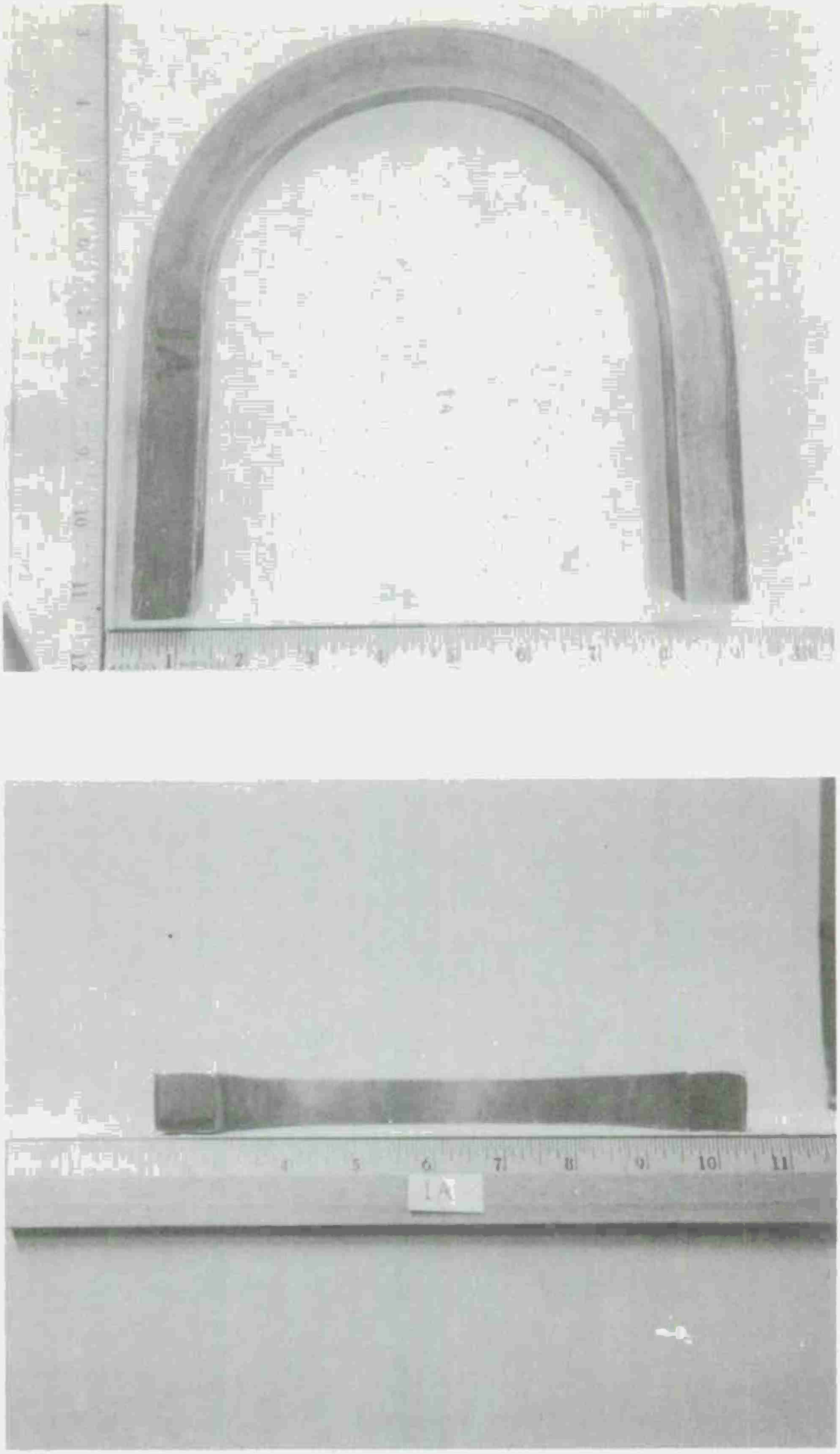


Figure 2. U-bend used in tests. Above: side view. Below: end view.

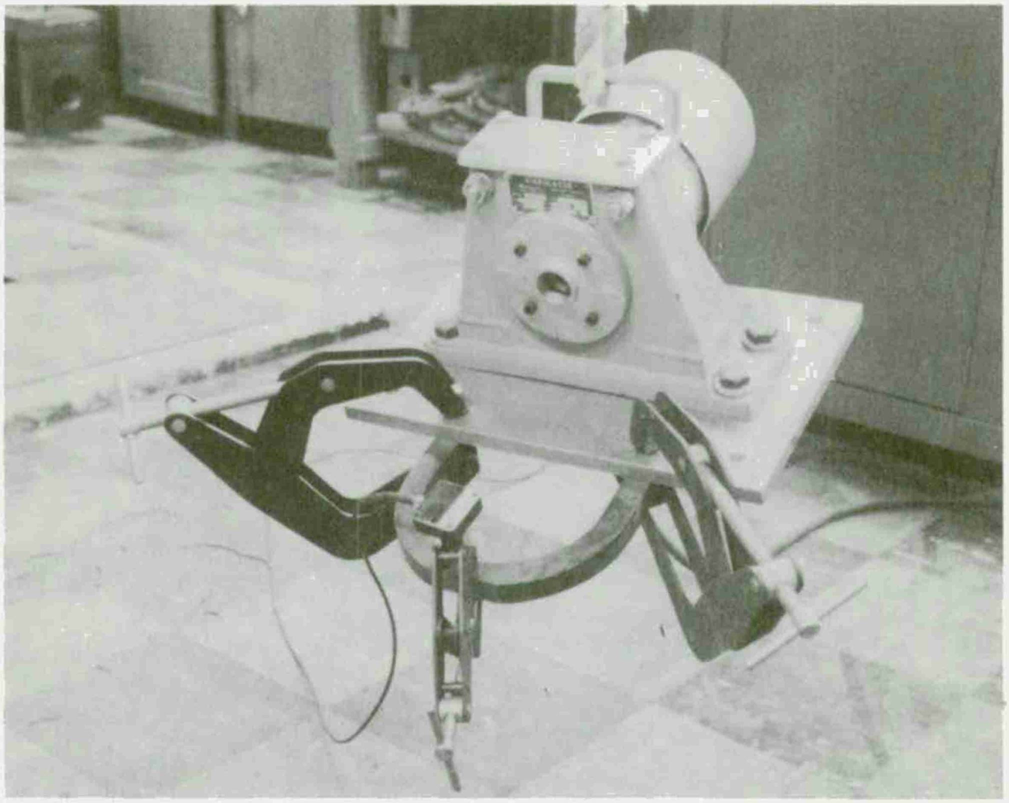


Figure 3. U-bend, clamped to the vibrator.

The frequency settings of the maximum resonance peaks for each U-bend are as follows:

U-Bend	Frequency (C/S)
Group 1A-5A-7A – Motor Eccentricity: 20 percent	
1A	115
	615
	668
	690
5A	208
	410
	550
	655
7A	206
	338
	360
	580

U-Bend	Frequency (C/S)
Group 2A-3A-4A – Motor Eccentricity: 45 percent	
2A	220 450 490 545
3A	108 229 368 415
4A	220 303 373 478

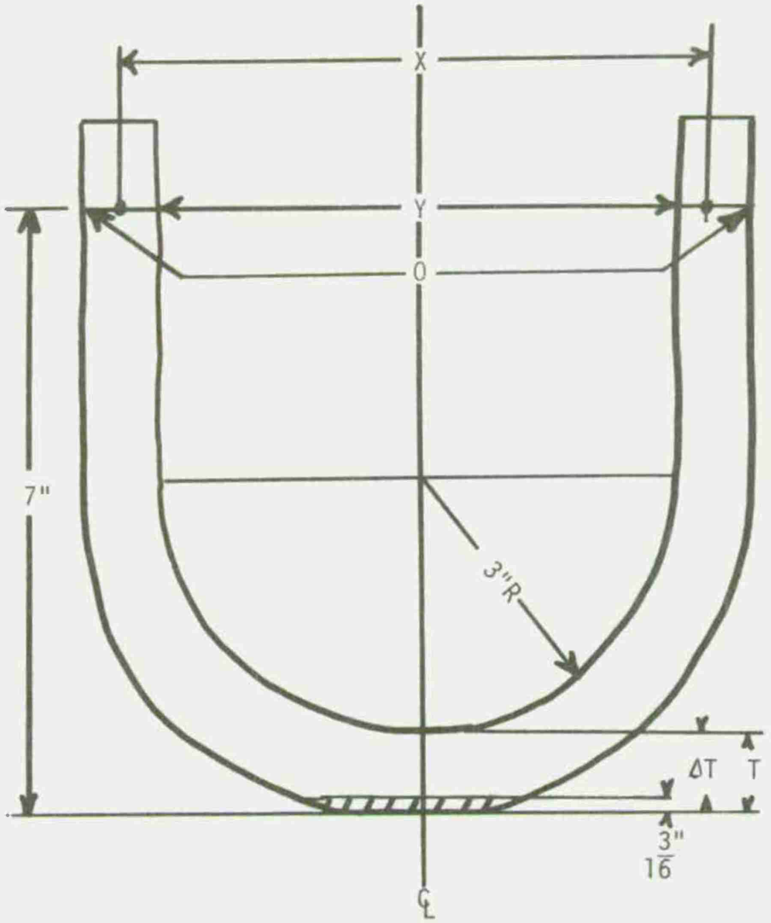
In all instances, the vibration time was 15 minutes.

After the vibration tests were completed, a flat, perpendicular to the U-bend centerline and 3/16 inch deep, was milled across the outside radius of the curve on all U-bends, as shown by the shaded area in Figure 4. The U-bends were then remeasured as before.

Data from the measurements in the XY-plane; positions X, Y, 0, and T; and along the Z-axis are given in Tables 2 and 3. The subscript (i) represents the initial measurement, the subscript (f) represents the measurement after milling, (Δ) is the difference between the two measurements, and (% Δ i) is the percent change from the initial measurement.

6. **U-Bend Specimens.** The set of U-bend specimens was designed to generate residual stresses by taking the form of eight U-bends cold formed around a 3-inch mandrel from 7/8- by 7/8- by 18-inch SAE 1020 bar stock (see Figure 2). Five samples were similarly formed by hot working to form the set containing no residual stress.

a. **Test and Measurement Procedure.** The cold-formed U-bend specimens were labeled 1A through 8A, and the hot-worked specimens were labeled 1B through 5B. Each specimen was scribed and measured as illustrated in Figure 4. The cold-formed U-bends were arranged into three groups so that the standard deviations of measurement Y(i) were almost equal. Specimens 1A-5A-7A and 2A-3A-4A formed the groups to be vibrated in order to determine the effects of vibration on residual stresses and dimensional stability. Specimens 6A-8A were left as-formed to represent the state of no stress relief. The hot-worked U-bends, 1B through 5B, formed the thermally



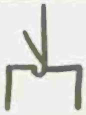
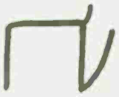
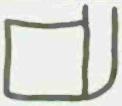
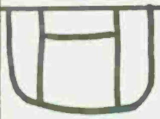
POSITION	DIAGRAM	DESCRIPTION
X		Outer diameter of gage hole to outer diameter of gage hole
Y		From inside 7" scribeline to inside 7" scribeline
O		From 7" scribeline to 7" scribeline. Calipers flush with bottom
T		At centerline calipers flush with bottom

Figure 4. U-bend measurements.

Table 2. U-Bend Arm Measurements (XY-Plane) (Inches)

Sample	X(i)	X(f)	Δ X	% Δi	Y(i)	Y(f)	Δ Y	%Δi	0(i)	0(f)	Δ 0	% Δi
					Vibrated U-Bends – Motor Eccentricity: 20 Percent							
1A	7.580	7.586	0.006	0.079	6.673	6.688	0.015	0.225	8.425	8.434	0.009	0.107
5A	7.646	7.659	0.013	0.170	6.732	6.744	0.012	0.178	8.482	8.489	0.007	0.083
7A	7.522	7.534	0.012	0.160	6.606	6.614	0.008	0.121	8.360	8.367	0.007	0.084
$\bar{X}$	7.583	7.593	0.010	0.136	6.670	6.682	0.012	0.175	8.422	8.430	0.008	0.091
σ	0.062	0.063	3.8×10^{-3}	0.050	0.063	0.065	3.5×10^{-3}	0.052	0.061	0.061	0.0012	0.014
					Vibrated U-Bends – Motor Eccentricity: 45 Percent							
2A	7.626	7.633	0.007	0.092	6.704	6.716	0.012	0.179	8.459	8.466	0.007	0.083
3A	7.501	7.511	0.010	0.133	6.588	6.597	0.009	0.137	8.339	8.346	0.007	0.084
4A	7.505	7.518	0.013	0.173	6.625	6.635	0.010	0.151	8.374	8.382	0.008	0.096
$\bar{X}$	7.544	7.554	0.010	0.133	6.639	6.649	0.010	0.156	8.391	8.398	0.007	0.088
σ	0.071	0.069	0.003	0.041	0.059	0.061	1.5×10^{-3}	0.021	0.061	0.062	5.8×10^{-4}	7.2×10^{-3}
					As-Formed U-Bends							
6A	7.613	7.617	0.004	0.053	6.715	6.723	0.008	0.119	8.469	8.475	0.006	0.071
8A	7.529	7.535	0.006	0.080	6.631	6.639	0.008	0.121	8.372	8.384	0.012	0.143
$\bar{X}$	7.571	7.576	0.005	0.067	6.673	6.681	0.008	0.120	8.420	8.430	0.009	0.107
σ	0.059	0.058	1.4×10^{-3}	0.019	0.059	0.059	*	1.4×10^{-3}	0.068	0.064	1.2×10^{-3}	0.051
					Hot-Worked U-Bends							
1B	6.883	6.884	0.001	0.015	5.991	5.992	0.001	0.017	7.756	7.756	0.000	0.000
2B	6.867	6.869	0.002	0.029	5.987	5.989	0.002	0.033	7.736	7.737	0.001	0.013
3B	6.801	6.800	0.001	0.015	5.907	5.908	0.001	0.017	7.667	7.668	0.001	0.013
4B	6.843	6.843	0.000	0.000	5.934	5.935	0.001	0.017	7.698	7.698	0.000	0.000
5B	6.891	6.894	0.003	0.044	5.992	5.993	0.001	0.017	7.751	7.752	0.001	0.013
$\bar{X}$	6.857	6.858	0.001	0.021	5.962	5.963	0.001	0.020	7.722	7.722	0.001	0.008
σ	0.036	0.038	1.1×10^{-3}	0.017	0.039	0.039	4.5×10^{-4}	7.2×10^{-3}	0.038	0.038	5.5×10^{-4}	7.1×10^{-3}

* Not determined.

Subscript	Represents
(i)	Initial Measurement
(f)	Final Measurement (After Milling)
(Δ)	Difference between Initial and Final Measurements
(% Δi)	Percent Change From Initial Measurement

Symbol	Represents
X,Y,O	Position of Measurements in XY-Plane, as in Figure 4
$\bar{X}$	Mean
σ	Standard Deviation

Table 3. Additional U-Bend Arm Measurements (XY-Plane and Z-Axis) (Inches)

U-Bend Arm Measurement (XY-Plane)					U-Bend Arm Measurement (Z-Axis)				
Sample	T(i)	T(f)	Δ T	% Δi	Sample	Initial	Final	Δ	% Δi
				Vibrated U-Bends					
1A	0.881	0.697	0.184	20.89	1A	0.031	0.038	0.007	22.58
5A	0.880	0.692	0.188	21.36	5A	0.052	0.062	0.010	19.23
7A	0.882	0.695	0.187	21.20	7A	0.037	0.050	0.013	35.14
$\bar{X}$	0.881	0.695	0.186	21.15	$\bar{X}$	0.040	0.050	0.010	25.65
σ	0.001	2.5×10^{-3}	2.1×10^{-3}	0.239	σ	0.011	0.012	0.003	8.388
				Vibrated U-Bends					
2A	0.881	0.688	0.193	21.91	2A	0.044	0.050	0.006	13.64
3A	0.881	0.705	0.176	19.98	3A	0.043	0.060	0.017	39.53
4A	0.880	0.696	0.184	20.91	4A	0.037	0.056	0.019	51.35
$\bar{X}$	0.881	0.696	0.184	20.93	$\bar{X}$	0.041	0.055	0.014	34.84
σ	5.8×10^{-4}	8.5×10^{-3}	8.5×10^{-3}	0.965	σ	0.004	0.005	0.007	19.29
				As-Formed U-Bends					
6A	0.887	0.700	0.187	21.08	6A	0.044	0.062	0.018	40.91
8A	0.883	0.692	0.191	21.63	8A	0.054	0.058	0.004	7.41
$\bar{X}$	0.885	0.696	0.189	21.36	$\bar{X}$	0.049	0.060	0.011	24.16
σ	2.8×10^{-3}	5.7×10^{-3}	2.8×10^{-3}	0.389	σ	0.007	0.003	0.010	23.69
				Hot-Worked U-Bends					
1B	0.880	0.691	0.189	21.48	1B	0.000	0.00	0.00	0.00
2B	0.878	0.705	0.173	19.70	2B	0.00	0.00	0.00	0.00
3B	0.873	0.691	0.182	20.85	3B	0.00	0.00	0.00	0.00
4B	0.873	0.694	0.179	20.50	4B	0.038	0.045	0.007	18.42
5B	0.887	0.696	0.191	21.53	5B	0.00	0.00	0.00	0.00
$\bar{X}$	0.878	0.695	0.183	20.81	$\bar{X}$	0.008	0.009	0.001	3.68
σ	5.8×10^{-3}	5.8×10^{-3}	7.4×10^{-3}	0.758	σ	0.017	0.020	0.003	8.24

Subscript	Represents
(i)	Initial Measurement
(f)	Final Measurement (After Milling)
(Δ)	Difference between Initial and Final Measurement
(% Δi)	Percent Change from Initial Measurement

Symbol	Represents
T	Position of Measurements in XY-Plane, as in Figure 4
$\bar{X}$	Mean
σ	Standard Deviation

treated group representing the state of complete stress relief. Besides measurements in the XY-plane to determine arm movement after machining, measurements also were taken along the Z-axis to determine vertical arm movement. Each U-bend was laid flat on a steel sheet with the height of the arms above the plate measured at the 7-inch scribe line. All U-bends were magnafluxed to detect the presence of cracks or flaws as shown in Figure 5. None were found.

Vibrational conditioning was performed with the vibration equipment shown in Figure 6. The vibrations are produced by using a variable speed motor driving an adjustable, eccentric weight. Instrumentation enables determination of the frequency settings corresponding to resonance peaks. At least three resonance peaks are to be located, and vibrations are to be held for 10 to 15 minutes each.[10]

b. **Results and Discussion**. The percent change from the initial measurements taken in position X shows that the as-formed U-bends, 6A-8A, exhibited less distortion than the U-bends in either of the vibrated groups, 1A-5A-7A and 2A-3A-4A. The range of the mean plus or minus the standard deviations of the vibrated groups fall together and do not overlap the mean plus or minus the standard deviation of the as-formed group, which is lower than the vibrated groups. Looking at the percent change from the initial measurements taken in position Y, one can see the same results as the measurements taken in position X.

The percent change from the initial measurements taken in position 0 differed from those taken in positions X and Y. In this case, the mean plus or minus the standard deviations of the vibrated groups again fall together but overlap the lower part of the range of the as-formed group. The means of the vibrated groups are also lower than those of the as-formed group. The measurements taken in positions X, Y, and 0 should yield similar results. The difference probably lies in the measurement techniques at the various positions and is enhanced by the small order of magnitude.

The differences in measurement at the various positions are relatively insignificant between the vibrated and as-formed groups when compared to the differences versus the hot-worked group, which exhibit virtually no distortion after milling. The validity of the results is strengthened by the fact that the percentage of material removed by milling was extremely uniform between all U-bends, thereby establishing similar conditions for arm movement in each.

The distortions in the XY-plane were of a small order of magnitude and leave inconclusive the effects of vibration in relieving residual stresses. More revealing are the measurements of U-bend arm movement along the Z-axis as recorded in Table 3.

---

[10] *VSR-Vibration Stress Reduction and Metal Stabilization Process Brief*, Martin Engineering Company.

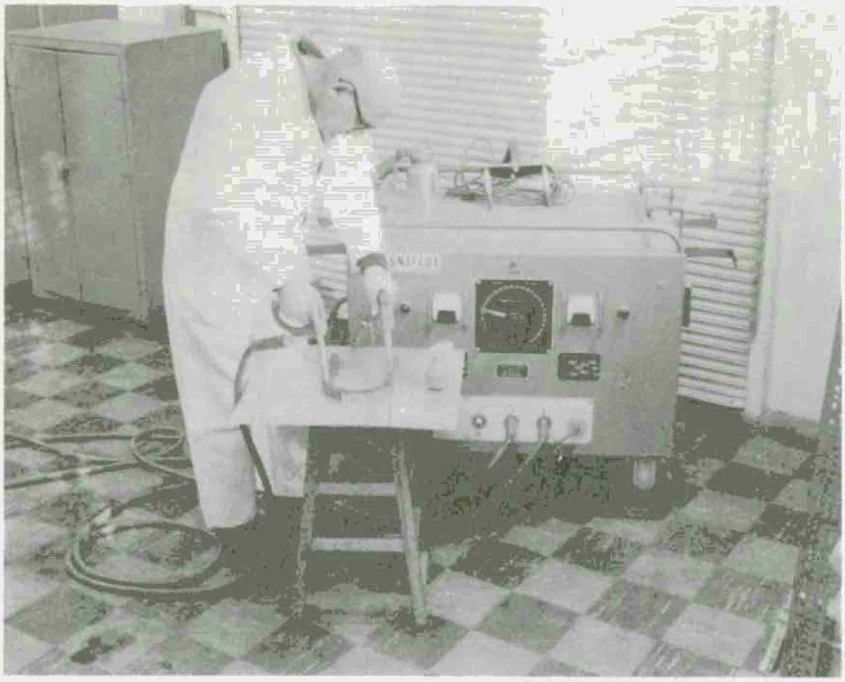


Figure 5. Magnafluxing a U-bend.

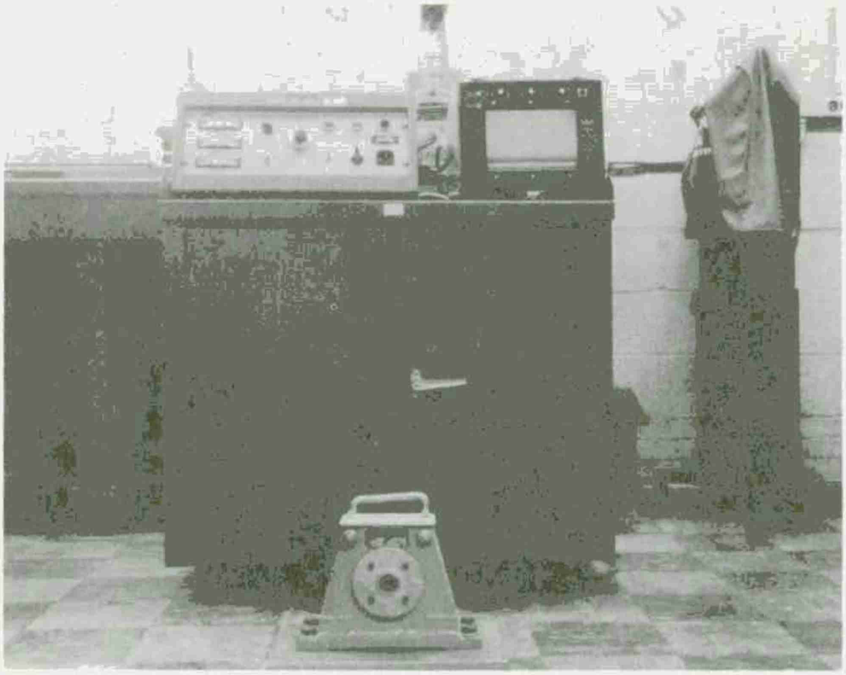


Figure 6. Vibration equipment.

The as-formed and vibrated U-bends showed large percentage increases in arm movement after milling while the hot-worked U-bends showed negligible arm movement. The as-formed U-bends, 6A-8A, exhibited slightly less movement than the vibrated group, 2A-3A-4A. When the vibrated and as-formed groups are compared to the hot-worked group, much greater differences are obtained which make the differences between the vibrated and as-formed groups, though sizable, seem insignificant. These results make it obvious that vibrations do not relieve residual stresses or impart dimensional stability.

Statistical analysis can be applied to the data to indicate if the differences between the groups are attributable to treatment or random specimen distribution. The statistical analysis used is the student t distribution:

$$t = \frac{\overline{X}_1 - \overline{X}_2}{\sqrt{\dfrac{\Sigma_i(\overline{X}_{1i} - \overline{X}_1)^2 + \Sigma_i(\overline{X}_{2i} - \overline{X}_2)^2}{N_1 + N_2 - 2} \left(\dfrac{1}{N_1} + \dfrac{1}{N_2}\right)}}$$

From appropriate tables, the value p, representing probability, is found for the respective t and number of degrees of freedom. The p values for comparison between U-bend groups are given in Table 4.

Table 4. Student t Test – p Values for U-Bends

Measurement Parameter	Comparison with Group (6A-8A) p Values Group (1A-5A-7A)	Group (2A-3A-4A)	Group (1B through 5B)
X	0.2	0.1+	0.02
I	0.2	0.1+	0.001
O	0.6	0.5	0.01
T	0.5	0.6	0.4
Arm Vertical Movement	0.9	0.6	0.1+

In engineering practice, values of p less than 0.1 are considered to indicate a significant difference.

Comparing the percentage change from initial measurement (% Δ i) for positions X, Y, and 0 of the arm opening in the XY-plane by the student t distribution yields some interesting results. The as-formed group, 6A-8A, was compared with the two vibrated groups, 1A-5A-7A and 2A-3A-4A, which gave p values for positions X, Y, and 0 greater than 0.1. This indicates that the difference was probably caused by random distribution of specimens. When the as-formed group was compared to the hot-worked group for each position, the p values were considerably less than 0.1 indicating a significant difference because of the thermal treatment. A similar comparison of measurement T, representing the percentage of material removed, gave p values of between 0.4 and 0.6. The differences were attributable to random sample distribution rather than to any other factors.

When the vertical arm movement was measured, it was found, from comparing the as-formed to the hot-worked and vibrated groups for each position, that the p values were greater than 0.1. The vibrated groups exhibited considerably higher probability that the differences were attributable to random distribution than did the hot-worked group for each position.

7. **Welded Test Samples.** A welded test plate, ¼ by 18 by 20 inches, was fabricated from material conforming to ASTM Standard A36. The plate was cut into two halves, each 20 by 9 inches, with each half double-beveled 60° along a 9-inch edge. The halves were then welded together using an E-7018 electrode corresponding to AWS 501. The weld test plate was again cut in half, perpendicular to the weld, forming two halves, each measuring 10 by 18 inches. One half was then annealed for 1 hour at 1,200° F (see Figure 7). Both halves were X-rayed to determine the soundness of the weld. Six tensile specimens were then cut from the as-welded plate, and three tensile specimens were cut from the annealed plate in accordance with ASTM standard E8, sheet-type, rectangular tensile specimens, such that the weld material contained no flaws as illustrated in Figures 8 and 9. From the as-welded plate, a vibration plate, 3 by 8½ inches, was cut with the weld in the transverse direction. The weld contained two small areas of porosity as depicted in Figure 8.

a. **Tensile Specimens.**

(1) **Test and Measurement Procedure.** The as-welded tensile specimens were marked from 1A to 6A, and the annealed tensile specimens were marked from 1H to 3H, as depicted in Figures 8 and 9. Tensile specimens 1A, 2A, and 3A formed the as-welded group; tensile specimens 4A, 5A, and 6A formed the group to be vibrated; and the annealed tensile specimens formed the third group, as described in Table 5. Each tensile specimen of group 4A-5A-6A was vibrated with motor eccentricity set at 20 percent as shown in Figure 10. The frequency settings for each tensile specimen are as follows:

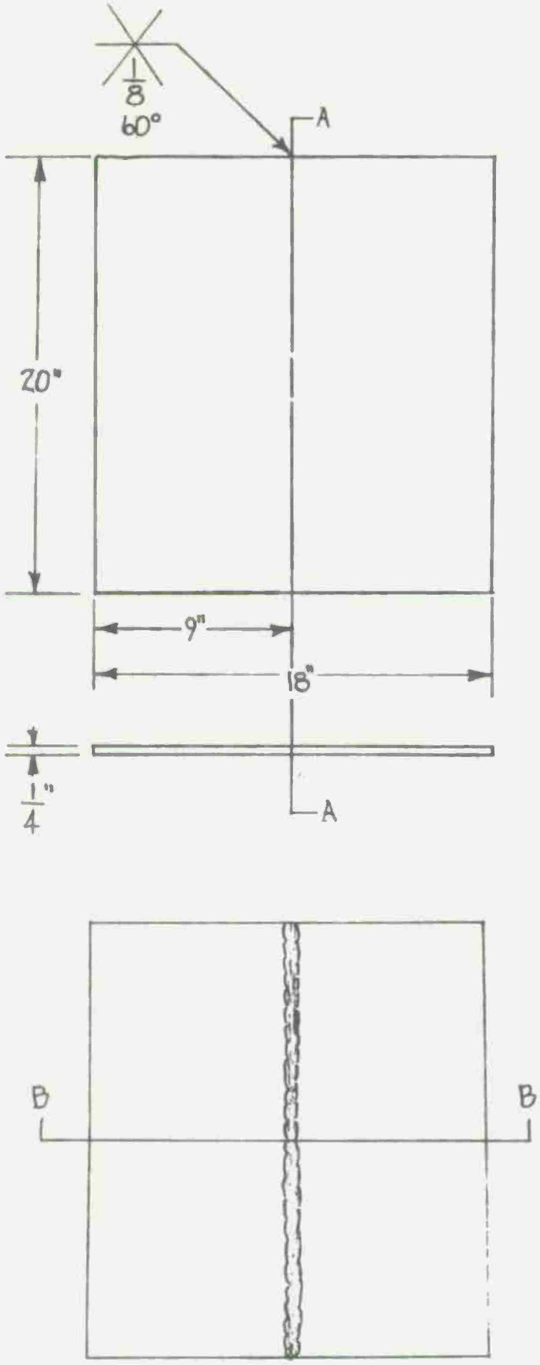


PLATE MATERIAL: ASTM A36
CUT PLATE IN HALF ALONG $\overline{AA}$
DOUBLE BEVEL EDGES ALONG $\overline{AA}$, 60°
WELD PLATE TOGETHER ALONG $\overline{AA}$
ELECTRODE: 7018

CUT WELDED PLATE IN HALF AT $\overline{BB}$
STRESS RELIEVE ONE HALF AT 1200°F

Figure 7. Welded test plate.

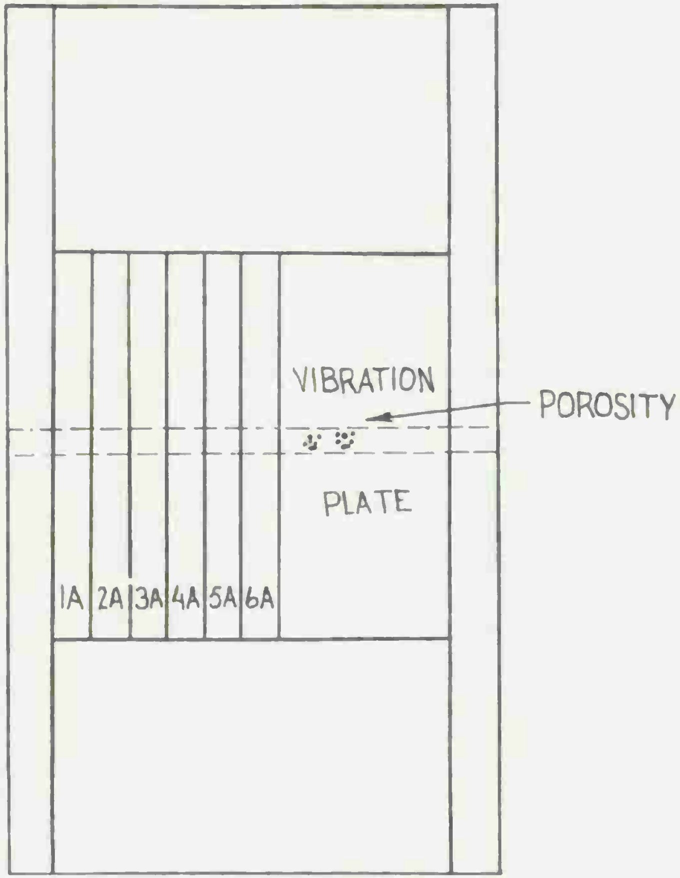


Figure 8. Sketch of the as-welded test plate.

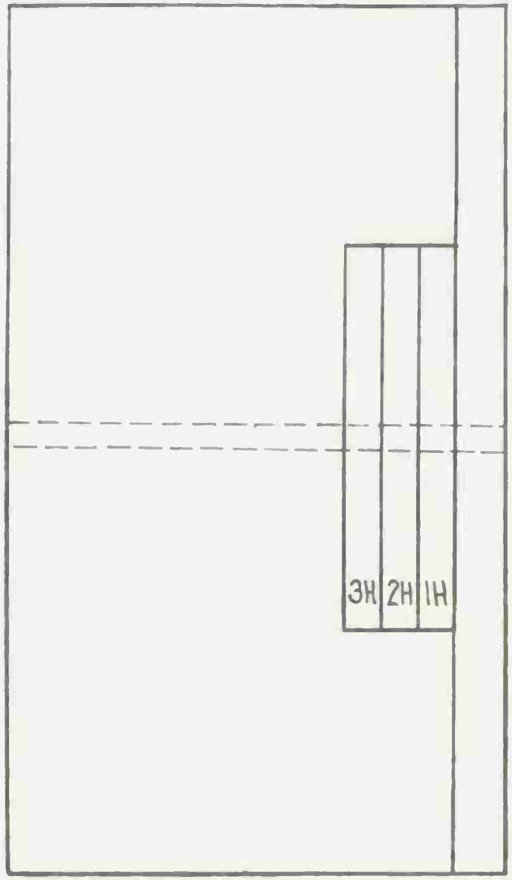


Figure 9. Sketch of the annealed test plate.

Specimen	Speed (X10 c/min)
4A	240
	370
	473
5A	235
	345
	483
6A	223
	335
	397

In all instances, the length of vibration time was 15 minutes. All tensile specimens were then tested on a 300,000-pound-load-capacity Baldwin.

Table 5. Tensile Specimen Groups

Group	Condition	Stress Relief Method
1A-2A-3A	As-welded	No stress relief
4A-5A-6A	Vibrated at 20 percent motor eccentricity	Vibration
1H-2H-3H	Annealed	No residual stress

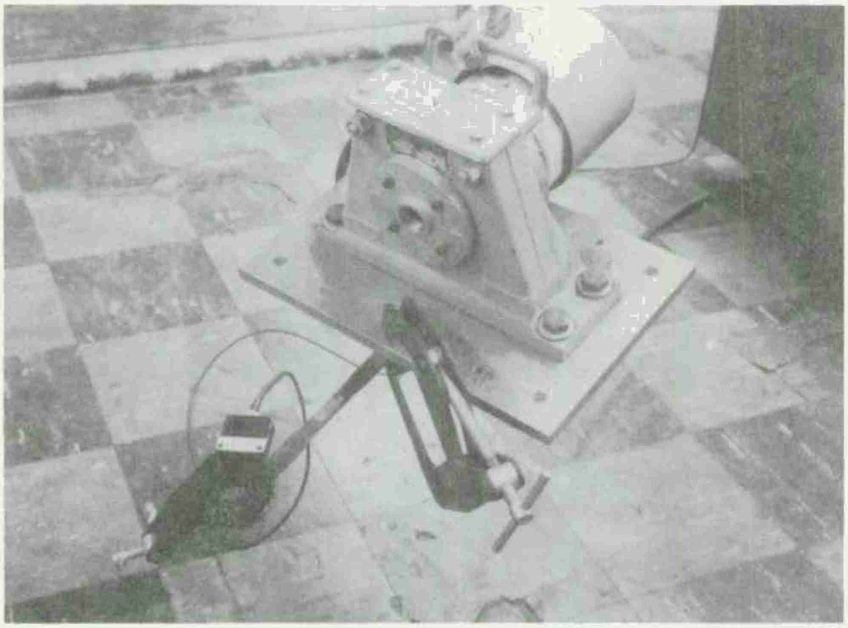


Figure 10. Tensile specimen clamped to the vibrator.

Universal Testing Machine using the 0- to 60,000-pound range in accordance with ASTM Standard E8. A load-strain recorder and 2-inch gage extensiometer were used to obtain load-strain curves in order to determine the ultimate tensile strength, 0.2-percent-offset yield strength, and Young's modulus for each tensile specimen.

(2) **Results and Discussion.** The results of the tensile test of the welded tensile specimens are given in Table 6. The p values calculated from group comparison using the student t test are given in Table 7. The tensile strength, yield strength, and elongation of the as-welded and vibrated tensile specimens show virtually no difference between groups; whereas, the annealed tensile specimens show slightly lower values for these parameters when compared to the other groups. The p values from comparing the as-welded and vibrated specimens indicate that the differences are probably attributable to random distribution. The p values from comparing the as-welded to annealed tensile specimens indicate a significant difference because of thermal treatment.

Table 6. Mechanical Properties of Tensile Specimens

Sample	Tensile Strength (lbf/in^2)	Yield Strength (lbf/in^2)	Elongation (pct)	Young's Modulus (10^6 lbf/in^2)
		As Welded		
1A	62,951	42,101	20.3	32.08
2A	62,489	46,916	20.6	27.95
3A	62,951	47,113	20.1	32.08
Average	62,797	45,377	20.3	30.7
		Vibrated		
4A	63,038	46,028	*	30.02
5A	61,977	42,384	*	29.59
6A	62,548	41,962	20.3	*
Average	62,521	43,458	20.3	29.8
		Annealed		
1H	61,872	42,185	23.4	29.33
2H	59,595	39,059	23.1	28.99
3H	59,048	40,039	23.0	28.31
Average	60,172	40,440	23.2	28.9

* Not determined.

Table 7. Student t Test – p Values for Tensile Specimens

Parameter	p Values	
	Group (1A-2A-3A) vs (4A-5A-6A)	Group (1A-2A-3A) vs (1H-2H-3H)
Tensile Strength	0.4	0.05–
Yield Strength	0.4	0.05+

b. **Welded Vibration Plate.** The as-welded vibration plate was vibrated in numerous harmonic modes, X-rayed, and magnafluxed, as shown in Figures 11 and 12. The vibration modes were as follows:

Speed (X10 c/min)		Time (hr)
258		1
518		2
470		2
490		3
550		17
	Total	25

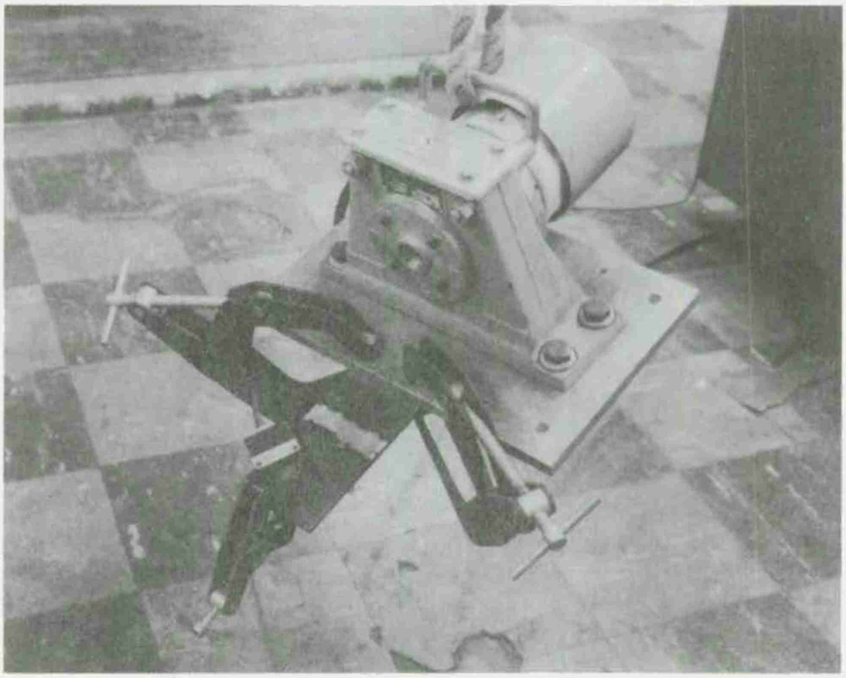


Figure 11. Vibration plate clamped to the vibrator.

Figure 12. Magnafluxing the vibration plate.

The motor eccentricity was 20 percent. The plate displayed no evidence of crack nucleation and/or propagation. For this particular specimen, fatigue damage from vibration is not evident; however, this does not mean such damage cannot occur, for larger, more complex forms could vibrate in such a manner as to suffer fatigue damage.

IV. CONCLUSIONS

8. **Conclusions.** From the foregoing analysis, vibration showed little, if any, significance as a means of residual stress relief or dimensional stabilization. The results showed that for cold-formed U-bends, vibratory stress relief does not relieve residual stresses. The effect of vibration on dimensional stability is also questionable. The probability that any difference between the as-formed and vibrated test specimens is attributable to random sample distribution is too great to allow a definitive conclusion. Thermal treatment is definitely a significant stress reliever, yielding positive results. For relief of residual stresses or for obtaining dimensional stability in cold-formed U-bends or similar shapes, vibratory stress relief just does not suffice, whereas, thermal stress relief or hot working will accomplish these tasks more uniformly and consistently.

The tensile test performed on the welded tensile specimens was used to determine mechanical properties and the effects that vibration had upon them. The only conclusion that can be drawn is that vibration has very little, if any, effects upon these properties and, therefore, does not change the brittle state of the weld material or heat-affected zone.

This analysis exemplifies the need for more experimental data on many types of residual stresses in a variety of forms. More importantly, a change in experimental technique is needed to change residual stress determination from qualitative to quantitative terms. Taking this consideration into account, we may use the quantitative results primarily to determine the effects of vibration on dimensional stability. The Metallurgy Research Team plans to conduct experimentation of residual stress relief by vibration in quantitative terms by utilizing the Mossbauer Surface Stress Analyzer to obtain actual residual stress levels in the near future.

DISTRIBUTION FOR USAMERDC REPORT 2150

No. Copies	Addressee
	Department of Defense
1	Director, Technical Information Defense Advanced Research Projects Agency 1400 Wilson Blvd Arlington, VA 22209
1	Director Defense Nuclear Agency ATTN: STTL Washington, DC 20305
12	Defense Documentation Center Cameron Station Alexandria, VA 22314
	Department of the Army
6	Commander US Army Materiel Command ATTN: AMCRD-WB AMCRD-T AMCRD-J AMCRD-O AMCRD-G AMCRD-FP 5001 Eisenhower Ave Alexandria, VA 22333
1	Commander US Army Troop Support Command ATTN: AMSTS-K 4300 Goodfellow Blvd St. Louis, MO 63120
1	Commander, HQ TRADOC ATTN: ATEN-ME Fort Monroe, VA 23651
1	HQDA (DAMA-AOA-M) Washington, DC 20310
1	HQDA (DAEN-RDL) Washington, DC 20314
1	HQDA (DAEN-MCE-D) Washington, DC 20314
1	Commander US Army Missile Command ATTN: AMSMI-RR Redstone Arsenal, AL 35809
1	Chief, Engineer Division DCSLOG ATTN: AFKC-LG-E HQ Sixth US Army Presidio of San Francisco, CA 94129
1	Commander Rock Island Arsenal ATTN: SARRI-LPL Rock Island, IL 61201
1	Director Army Materials and Mechanics Research Center ATTN: AMXMR-STL Technical Library Watertown, MA 02172
1	Commander US Army Natick Laboratories ATTN: Technical Library Natick, MA 01760
1	US Army Ballistic Research Laboratories Technical Library AMXBR-LB (Bldg 305) Aberdeen Proving Ground, MD 21005
1	Commander Edgewood Arsenal ATTN: SAREA-TS-L Aberdeen Proving Ground, MD 21010
1	Commander US Army Aberdeen Proving Ground ATTN: STEAP-MT-U (GE Branch) Aberdeen Proving Ground, MD 21005
1	Director US Army Materiel Systems Analysis Agency ATTN: AMXSY-CM Aberdeen Proving Ground, MD 21005

No. Copies	Addressee
1	Director US Army Engineer Waterways Experiment Station ATTN: Chief, Library Branch Technical Information Center Vicksburg, MS 39180
1	Commander Picatinny Arsenal ATTN: SARPA-TS-S No. 59 Dover, NJ 07801
1	Plastics Technical Evaluation Center Picatinny Arsenal, Bldg 176 ATTN: A. M. Anzalone SARPA-FR-M-D Dover, NJ 07801
1	Commander Frankford Arsenal ATTN: Library, K2400, Bl 51-2 Philadelphia, PA 19137
1	Learning Resources Center US Army Engineer School Library Bldg 270 Fort Belvoir, VA 22060
1	Director, Special Forces School US Army Institute for Military Assistance ATTN: Training Division Fort Bragg, NC 28307
1	President US Army Airborne, Communications and Electronics ATTN: STEBF-ABTD Fort Bragg, NC 28307
1	Commander Headquarters, 39th Engineer Battalion (Cbt) Fort Devens, MA 01433
1	President US Army Armor and Engineer Board ATTN: ATZK-AE-TD-E Fort Knox, KY 40121
1	Commandant US Army Command and General Staff College ATTN: ATSW-RI-L Fort Leavenworth, KS 66027
2	Director Petrol & Fld Svc Dept US Army Quartermaster School Fort Lee, VA 23801
1	Commander US Army Electronics Command ATTN: AMSEL-GG-TD Fort Monmouth, NJ 07703
1	President US Army Aviation Test Board ATTN: STEBG-PO Fort Rucker, AL 36360
1	US Army Aviation School Library P.O. Drawer 0 Fort Rucker, AL 36360
1	HQ, 193D Infantry Brigade (CZ) Directorate of Facilities Engineering Fort Amador, Canal Zone
1	Commander Special Forces Detachment (Airborne), Europe APO New York 09050
1	HQ, USAREUR & Seventh Army DCSENGR, ATTN: AEAEN-MO APO New York 09403
2	Engineer Representative US Army Standardization Group, UK Box 65, FPO New York 09510
1	Commander 2nd Engineer Group ATTN: S4 APO San Francisco 96301
1	Commander and Director USAFESA ATTN: FESA-RTD Fort Belvoir, VA 22060
	USAMERDC
1	Commander Technical Director Assoc Tech Director (R&D) Chief, Legal Office CIRCULATE

No. Copies	Addressee
1	Chief, Lab 1000 Chief, Lab 2000 Chief, Lab 3000 Chief, Lab 4000 Chief, Lab 5000 Chief, Lab 6000 Chief, Lab 7000 Chief, Lab 8000 Chief, Tech & Res Spt Ofc CIRCULATE
2	Lab 4000
30	Metallurgy Research Team
2	Tech Reports Ofc
3	Security Ofc
2	Tech Documents Ctr
1	Requirements & Programs Office
1	Information Ofc
1	Legal Ofc
	Department of the Navy
1	Director, Physics Program (421) Office of Naval Research Arlington, VA 22217
1	Director Naval Research Laboratory ATTN: Code 2627 Washington, DC 20375
1	Commander, Naval Facilities Engineering Command Department of the Navy ATTN: Code 032-A 200 Stovall St. Alexandria, VA 22332
1	US Naval Oceanographic Office Library (Code 1600) Washington, DC 20373
1	Officer-in-Charge (Code L31) Civil Engineering Laboratory Naval Construction Battalion Center Port Hueneme, CA 93043
1	Director Earth Physics Program Code 463 Office of Naval Research Arlington, VA 22217
	Department of the Air Force
1	HQ USAF/RDPS (Mr. Allan Eaffy) Washington, DC 20330
1	Mr. William J. Engle Chief, Utilities Branch HQ USAF/PREEU Washington, DC 20332
1	AFSC/INJ Andrews AFB, MD 20334
1	OL-AA AFCEC/DEZ Kirtland AFB, NM 87117
1	AFCEC/XR/21 Tyndall AFB, FL 32401
1	HQ USAF/PREES ATTN: Mr. Edwin B. Mixon Bolling AFB – Bldg 626 Washington, DC 20332
1	AFAPL/SFL Wright-Patterson AFB, OH 45433
1	ASD/ENCSP Wright-Patterson AFB, OH 45433
	Others
1	Professor Raymond R. Fox School of Engineering and Applied Science The George Washington University Washington, DC 20052
1	Department of Transportation Library, FOB 10A, TAD-494.6 800 Independence Ave., SW Washington, DC 20591

DEPARTMENT OF THE ARMY
U. S. ARMY MOBILITY EQUIPMENT
RESEARCH AND DEVELOPMENT CENTER
FORT BELVOIR, VIRGINIA 22060

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE, $300

POSTAGE AND FEES PAID
U. S. DEPARTMENT OF THE ARMY
DOD-314

U.S.MAIL

THIRD CLASS MAIL

Commander
Rock Island Arsenal
ATTN: SARRI-LPL
Rock Island, Il 61201